ENERGY CONSERVATION

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FOAM GLASS AND PROBLEMS OF ENERGY CONSERVATION

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Foam glass is one of the most promising and demanded materials for its heat-insulating properties and environmental cleanness in production and use. There has been a trend toward development of foam glass production in Russia. In the near future, no less than six foam glass production lines will be started up.

Foam glass has been known as heat- and sound-insulating material since the middle of the last century. Today, there is heightened interest in foam glass. This is due to the increase in fuel costs and worsening of energy problems. In Russia, 500 – 600 kW · h/m^2 of living space is consumed for heating residences. In Western Europe and North America, including Sweden, Canada, and Norway — countries with climatic conditions similar to Russia's, consumption is 120 – 140 kW · h/m^2. This corresponds to consumption of 74 kg of arb. fuel per m^2 in Russia in consideration of the hot water supply and 18 kg of arb. fuel per m^2 in Western countries. Of this amount, 40% is lost through walls, 23% is lost through windows, 10% through the basement, 18% through the roof, and 14% through ventilation [1].

SNiP 2-Sh-79 "Construction Heat Engineering" (new 2003 edition) allows power consumption of 160 kW · h/m^2 for heating.

Public utilities are the largest consumers of fuel and power. They are followed by transportation, metallurgy, the glass, cement, and chemical industries, etc. The most important way of solving the problem of energy conservation is thermal insulation of buildings that reduces fuel consumption for heating by a minimum of 25%.

The products of burning fuel are among the most important components of environmental pollution. Reducing fuel consumption will reduce harmful emissions into the atmosphere.

Foam glass is the most effective heat-insulating material with respect to technical characteristics. Foam glass has low thermal conductivity of 0.03 – 0.05 W/(m · K), high strength for heat-insulating materials, up to 1 MPa, moisture impermeability and inertness to water, bases and acids, and incombustibility; it has an unrestricted temperature of use in buildings, structures, refrigerator, and other technology. In contrast to organic and fiber heat-insulating materials, foam glass is a fire-resistant material with an unlimited lifetime. In addition to insulating the walls, roofs, and floors of buildings and structures, foam glass is used for insulating industrial refrigerators, ships, and marine oil terminals, as foundations in permafrost conditions, in atomic energy, where the requirements for fire safety are especially rigorous, for collection of petroleum products spilled in bodies of water, etc.

In the middle region of Russia, Siberia, and the Far East, the heat-transfer resistance of the walls of residences and office buildings is equal to 0.9 – 1.1 m^2 · K/W, which is 2.3 – 3.5 times lower than in Western Europe. SNiP 11-3-79 in the 1995 and 2000 editions established the standards for the minimum acceptable heat-transfer resistance of walls at 3.1 m^2 · K/W for Moscow and 3.35 – 3.75 m^2 · K/W for Siberia.

Despite the legislative restrictions related to fire and sanitary-hygienic (environmental) safety and short lifetime, foam plastics and heat-insulating slabs made of resins are still used for heating buildings. According to Rosstroi data, the total volume of heat-insulating materials used in construction in 2007 was 23 – 25 million m^3, and it will increase to 45 – 50 million m^3 by 2010, including industry and engineering systems. The production volume of all kinds of heat-insulating materials was 10 – 12 million m^3 in 2007.

Approximately 40 million m^2 of housing was delivered in 2004, 45 million m^2 in 2005, 54 million m^2 in 2006, and 80 – 90 million m^2 is projected for 2010, i.e., an annual increase in housing volumes of 11.5 – 12.5%. A 24% increase was predicted in 2007 (Rosstroi data) [2].

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TABLE 1

Articles	Density, kg/m^3	Compressive strength, kPa	Thermal conductivity, W/(m · K)	Maximum temperatures of use, °C	Water vapor permeability, mg/(m · h · Pa)	Combustibility	Environmental evaluation	Lifetime, years
Mineral wool products:								
heat-insulating tiles made of mineral wool on synthetic binders	200	40 – 120	0.066 – 0.060	100	0.380 – 0.600	Difficultly combustible	Toxic when burned (7 – 8% binder)	7 – 10
high-rigidity mineral-wool tiles	200	100	0.045	–	0.580	″	Toxic when burned (10% binder) and inhaled	10 – 12
glass staple fiber tiles	175 – 200	–	0.049	180	–	″	Toxic when burned (6% binder) and inhaled	7 – 10
Foam plastics:								
polystyrene foam	20 – 40	50 – 150	~ 0.038	70	0.050	Combustible	Toxic when burned	10 – 12
polyurethane foam	40 – 60	120 – 200	0.035	200	–	″	Same	10 – 12
Heat-insulating tiles made of reol resins	50 – 100	50 – 200	0.040 – 0.046	130	–	″	Harmful emissions	10 – 12
Cellular inorganic materials (foam concrete)	350	700 – 800	0.090 – 0.100	350	0.230	Incombustible	Environmentally clean	~ 10 (when protected from moisture)
Foam glass:								
blocks	120 – 200	≥ 700	0.050 – 0.080	450	0.001 – 0.004	″	″	Unlimited
gravel	80 – 100*	500 – 1000	0.030 – 0.050	450		″	″	″
Keramzit (gravel)	250 – 350	500 – 1500	0.210 – 0.230	450	0.21	″	″	Long-lived

* Specific bulk mass.

Due to the acute need to further increase energy conservation, higher rates of increase in use of heat-insulating materials should be anticipated. In view of the serious problems with fire safety, there is little impetus to develop production of competing materials — foam plastics and fire insulation.

The technical characteristics of heat-insulating materials are reported in Table 1 and show that foam plastics, widely used in construction, are hazardous with respect to fireproofing and toxicity. This was unfortunately previously confirmed in many large technogenic catastrophes (KamAZ, Rossiya Hotel, MVD building in Samara, many medical institutions, inns, etc.) which led to fatalities and large material losses.

Mineral-wool products have a limited lifetime, which is also confirmed by the experimental data.

The low thermal conductivity of foam plastics is due to the presence of gases with low thermal conductivity (much lower than air) in their pores, formed during manufacture of the material. These gases volatilize after six months as a result of diffusion and the pores fill with air. The thermal resistance of the material decreases by 25%. The material absorbs water vapors, which corrodes it, further decreases the thermal resistance, and causes compacting, and degradation.

Heat-insulating mats contain a minimum of 5% polymer binder. They do not burn, but they smolder and release toxic gases in a fire. These materials are subject to corrosion of both the polymer binders and the fibers.

In inspecting the glass viewing window in the Ostankino television tower after a fire, we found that the fiber and foam plastic insulation was totally destroyed. This was the 30th year of use, but the insulation had clearly been destroyed much earlier. Based on experience in using other objects, the lifetime of these types of thermal insulation is a maximum of 12 – 15 years. At the same time, foam glass remained in the initial condition and its lifetime is almost unlimited. It is necessary to note that the lifetime of buildings and structures is many times longer than the lifetime of fiber and foam plastic insulation.

The high water absorption of cellular materials (foam concrete) is a serious drawback due to the decrease in the thermal resistance, while freezing and destruction are observed in many cases.

Keramzit has 5 – 7 times higher thermal conductivity than foam glass gravel.

With respect to the technical characteristics, foam glass is thus the most suitable heat-insulating material. The following advantages of foam glass should be added:

possible use in different structures of walls, roofs, and in permafrost zones as a support instead of a foundation under buildings;

thermal insulation of ships and refrigerators;

sound insulation;

insulation of pipelines (shells, gravel, and granules), possible use as the basic construction material in moderate bearing loads in light structures, cowsheds, temporary housing and service premises in oilfields, construction sites, etc.;

use for collecting various petroleum products in soil and water;

use in atomic energy and other economic sectors where the fire safety requirements are especially rigorous;

possibility of combining insulation with the external facing of buildings by using glazed glass foam;

possibility of mechanical processing with a simple tool (steel saws, drills, etc.).

The initial batch for foam glass is a mixture of glass powder and foaming agents and natural inclusion of air between the particles of the components. There are three types of foam glass: blocks, gravel, and granules.

Blocks are manufactured by foaming the batch or slip in special molds, followed by annealing and cutting the intermediate products to obtain items of the required shape. The scraps of intermediate products are processed into gravel. Blocks can be made from a continuous ribbon. In this case, the batch is applied on the ribbon to a certain height. After foaming and annealing, the ribbon is cut and laid out into blocks. The maximum size of the blocks is $0.5 \times 0.4 \times 0.15$ m.

Gravel is the product of crushing wastes obtained in cutting blocks, cutting the ribbon, and cracking blocks and ribbon. The gravel size is 10 – 40 mm. Gravel can be made from a continuously moving ribbon by breaking it. In this case, the ribbon does not have to be annealed.

Granulated foam glass is made from granulated batch. The batch is granulated in drum and plate granulators, fluidized or fluid bed reactors, with or without a binder. Soda hydrates, sulfates, and water can be used as the binder. The granules are foamed and annealed. The granule size is 5 – 25 mm and the density is 2.5 – 2.6 g/cm^3. When caustic soda is used as the binder, the density of the granules increases to 2.7 – 3.0 g/cm^3 and the strength increases to 0.4 MPa.

The interest in using foam glass in construction and engineering is growing in all countries. It is not only a heat- and sound-insulating material but also an environmentally clean material both in production and in use. Estimations of production volumes and prices for heat-insulating materials in Russia and abroad are reported in Table 2.

Pittsburgh-Corning Europe (Belgium) is the largest manufacturer of foam glass in Europe, and the production volume is 860,000 m^3/year. Foam glass gravel is manufactured in Germany by the continuously moving ribbon method.

TABLE 2

Country	Type of heat insulation	Production volume per 1000 inhabitants, m^3	Price of 1 m^3, US dollars
Russia	All types	53	47 – 54* 78 – 120**
	Including foam glass	0.05	120 – 140 300 – 400*** 500****
Belarus	Foam glass	48	100
Japan	All types	350	–
	Including foam glass	50	300
Finland	All types	400	–
USA	All types	500	–
	Including foam glass	120	300 – 400
Germany	All types	70	–
Sweden	Same	600	–
Belgium	All types	350	–
	Including foam glass	85	150 – 200*****

* Polystyrene foam

** Mineral wool tiles.

*** In Moscow.

**** In Siberia.

***** In Europe.

There is one manufacturer of foam glass blocks and gravel by the flow method at Gomel’ Glass Works (Belarus) in CIS countries based on the situation in 2007. The production volume is approximately 36,000 – 40,000 m^3 a year. STES Company (Vladimir) and Perm’ Foam Silicates Plant manufacture insignificant volumes (2000 – 7000 m^3). There are pilot plants in Tomsk, Voronezh, and Belgorod.

The manufactured materials are usually used as concrete fillers, insulating filling in the walls of buildings, and insulation in pilot construction objects (nonbearing walls).

Several large in-line foam glass plants are in the design stage and no less than 5 – 6 industrial lines with a total capacity of 120,000 – 150,000 m^3 a year are expected to start up by 2010.

In addition to the basic raw materials for foam glass production — glass powder and a blowing agent (foaming agent) — coke, coal, graphite, chalk, modifiers are sometimes added as a function of the composition of the glass. The glass : foaming agent ratio (%) is (97.0 – 99.5) : (1.5 – 3.0). In addition to solid foaming agents, liquid and mixed foaming agents are also used. For example, a mixture of glycerin, liquid glass, and water. The glass:foaming agent ratio (%) in this case is 93.5 : 6.5. The initial glass can be in-house or purchased cullet or a mixture of in-house and purchased

TABLE 3

Glass	Mass content, %						
	SiO_2	Al_2O_3	CaO	MgO	Na_2O	SO_3	Fe_2O_3
Sheet:							
BBC*	71.80 – 72.40	1.80 – 2.20	6.40 – 7.00	3.80 – 4.30	14.50 – 14.90	< 0.50	< 0.20
float process and rolling	72.50 – 73.00	0.86 – 1.39	8.47 – 9.17	3.13 – 3.54	13.79 – 13.29	0.54 – 0.34	< 0.20
Bottle:							
colorless	71.50 – 72.50	1.40 – 1.60	9.10 – 9.30	2.10 – 2.30	14.40 – 14.80	0.40	< 0.40
green**	72.20	2.00	9.50	2.20	13.50	0.20	0.20

* In addition, 0.50 – 1.50% K_2O.

** In addition, 0.20% Cr_2O_3.

glass. The compositions of the most frequently used glasses are reported in Table 3.

Glass granulate of the compositions of vertically drawn sheet glass, float glass, rolled, colorless bottle, half-white, green glass and the glass cullet made from them is the initial raw material. The use of brown containers, electric-lamp and kinescope glass, and lead crystal requires additional processing.

The highest quality foam glass is made by melting the initial granulate in tank furnaces, including those widely used (including foam glass for construction engineering applications for insulation of refrigerators and oil and gas pipelines). Use of sheet glass and colorless and green container glass made in the form of granulate is proposed to ensure high quality and low cost of the foam glass. When there is an excess of in-house cullet from other plants, it can also be used after preliminary grinding in a roller or hammer crusher to less than 5 mm in size.

The technology for foaming foam glass blocks and gravel is discrete or noncontinuous, while production of granulated foam glass is noncontinuous-discrete and includes the operation of granulation of the initial batch.

In production of foam-glass blocks, the glass frit in the form of granulate or 5-mm chunks enter a ball mill. A powdered foaming agent is fed in (coal, coke, etc.). After the mill, the foam-glass batch is feed into a filling station and measured out into metal molds previously lubricated with an aqueous suspension of kaolin. The filled molds go by conveyor to a tunnel foaming furnace (27 m long, 2 m wide) fueled by natural gas. The foaming temperature is 850°C. An active-annealing stabilization furnace (17 m long, 1.98 m wide) and a cooling section (44 m long, 4.9 m wide) then follow.

The foamed foam-glass intermediate products have slanted edges to facilitate removing them from the mold. They enter the cutting section where they are shaped into rectangles measuring 475 × 400 × 120 mm (0.0228 m^3) with a density of 120 – 160 kg/m^3.

The block trimmings are crushed and used as gravel.

In production of glass foam gravel with continuous technology, the glass frit is fed into a mill and ground to a fineness of 250 μm, and 50% is smaller than 40 μm.

The composition of the foaming agent is: 85% liquid glass, 12% water, and 3% glycerin per 100 kg of powder. Then 7% is given above 100% of the foaming agent glass powder.

Requirements for Sodium Silicate

Silicate ratio (molar ratio of SiO_2 to Na_2O) . . . 3.41 – 3.51
Density, g/cm^3 . . . . 1.345 – 1.355
Composition, %:
Na_2O . . . . 7.8 – 8.2
SiO_2 . . . . 26.6 – 27.0

Requirements for Glycerin

Concentration, % 86.5
Density, kg/m^3 . . . . 1260 – 1263
Temperature, °C:
melting point . . . . 16 – 17
boiling point . . . . 259 – 290

The glass powder and foaming components then go into a mixer and the paste obtained is fed into a foaming furnace on a fiberglass fabric belt lubricated with kaolin to prevent the mixture from sticking. The continuous foam glass ribbon coming out of the furnace is broken into elementary sections based on the grooves in the furnace. The furnace has a length of 17.28 m and a useful width of 1.8 m. The maximum temperature in the furnace is 1050°C, the foaming temperature is 850°C, and natural gas is the fuel.

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